Near-real-time Satellite Cloud Products For Icing Detection And Aviation Weather Over The USA

Patrick Minnis, William L. Smith, Jr., Louis Nguyen

Atmospheric Sciences

NASA Langley Research Center, Hampton, VA

Patrick Heck & Mandy Khaiyer

AS&M, Inc., Hampton, VA

Acknowledgements

- **John Murray, ASAP/AVSP NASA LaRC**
- **Tom Ratvasky and NASA Glenn Twin Otter Icing Team**

OBJECTIVES

• Develop a satellite-based icing detection methodology that can be applied operationally with results provided in a timely manner as part of an integrated icing product for the aviation community

• Use satellite data to provide near-real time cloud-top & base altitudes for aviation weather applications

OUTLINE

- **DESCRIPTION OF METHODOLOGY AND CLOUD PRODUCTS**

  (Minnis)

- **RELATING AIRCRAFT ICING TO SATELLITE CLOUD PARAMETERS**

  (Smith)

- **DEMONSTRATION OF PROTOTYPE PRODUCT**

  (Minnis)

APPROACH

- **Use cloud properties currently being derived from satellite data at various time and space scales and relate them to aircraft icing**

-Developed & applied algorithms to various satellite (GOES, AVHRR, etc.) data for field programs for climate research

- Currently deriving global cloud and radiation parameters from EOS sensors for global change studies as part of the Clouds and Earth's Radiant Energy System (CERES) Experiment post processing

- Applying similar algorithms to 4-km GOES data to derive cloud and radiation parameters for DOE ARM program over SGP, for NASA CRYSTAL(FL), Icing (Midwest) running experimentally in R/T

PIXEL-LEVEL CLOUD PROPERTIES

EFFECTIVE RADIATING TEMP	Tc
EFFECTIVE HEIGHT, PRESSURE	Zc, pc
TOP PRESSURE, HEIGHT	p_t, z_t
THICKNESS	h
EMISSIVITY	[illegible]
PHASE (water or ice; 1 or 2)	P
WATER DROPLET EFFECTIVE RADIUS	re
OPTICAL DEPTH	[illegible]
LIQUID WATER PATH	LWP
ICE EFFECTIVE DIAMETER	De
ICE WATER PATH	IWP

Blue indicates utility for icing

ICING

ICING CONDITIONS ARE DETERMINED BY CLOUD

• liquid water content, *LWC*	**positive w/ intensity**
• temperature, *T(z)*	**negative w/ intensity**
• droplet size distribution, *N*(*r*)	***r*** **positive w/ intensity**

SATELLITE REMOTE SENSING CAN DETERMINE CLOUD

- optical depth, □
- effective droplet size, *re*
- liquid water path, *LWP*
- cloud top temperature, *Tc*
- thickness, *h*

IN CERTAIN CIRCUMSTANCES

CLOUD PRODUCTS VS. ICING PARAMETERS

- $LWP = LWC * h$

- $re = f[N(r)]$

- Tc & h can yield depth of freezing layer

- z_t is top of icing layer

- ceiling = $z_t - h$

IN MANY CASES, SATELLITE REMOTE SENSING
SHOULD PROVIDE ICING INFORMATION

DATA

- GOES-8 IMAGER (4KM RESOLUTION) 75° W

Visible	(0.63 μm; ch.1)
Solar Infrared	(3.9 μm; ch.2)
IR Window	(10.8 μm; ch.4)
Split Window	(12.0 μm; ch.5) (G-12: 13.3 μm)

Visible Channel Calibrated Following Minnis et al. 2002

- **Rapid Update Cycle (RUC) 20 km x 20 km hourly analyses**

  - surface air temperature => skin temperature
  - temperature & moisture profiles => absorption correction, heights

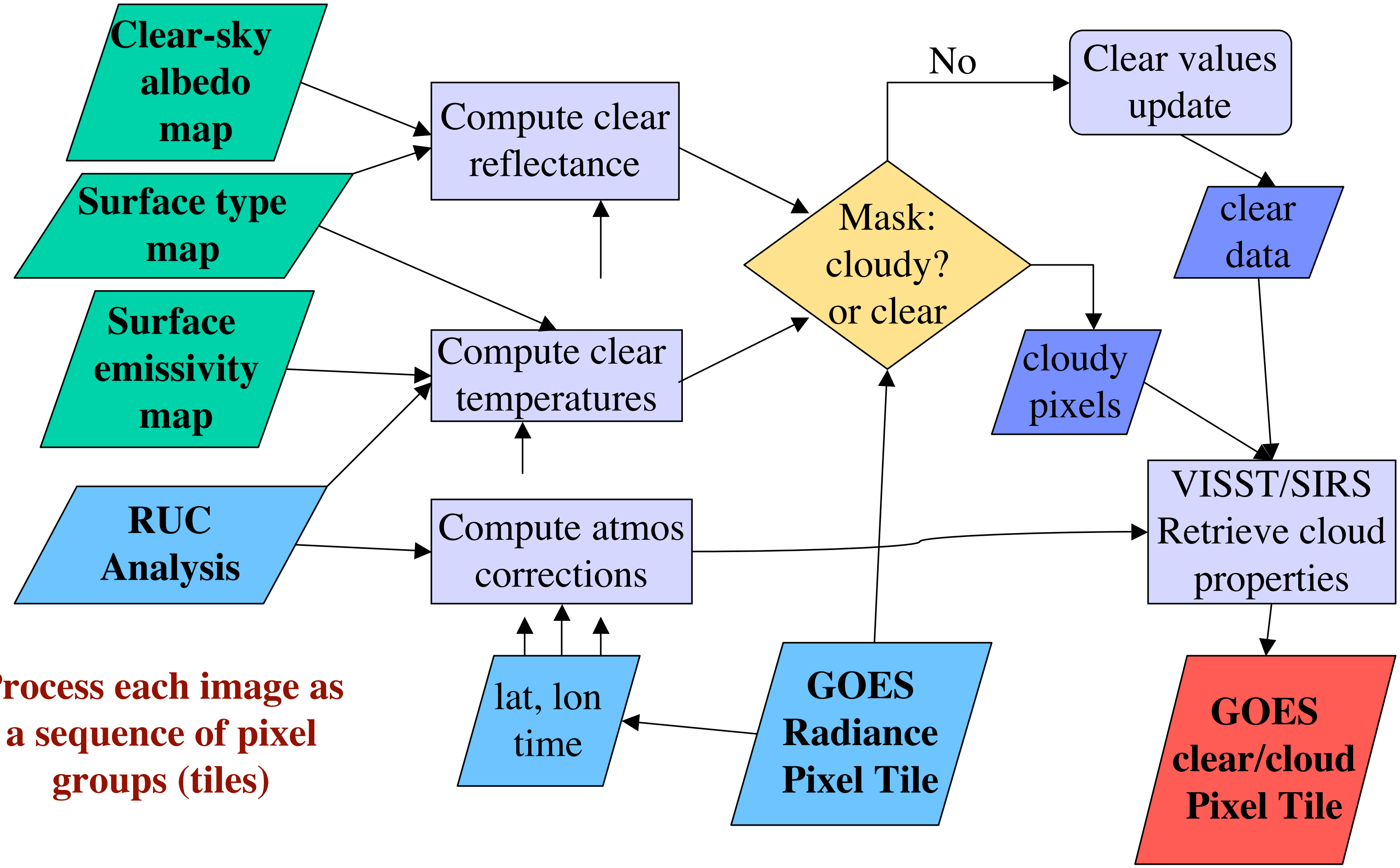
- **CERES clear-sky albedo, surface emissivity (10', 1°)**

  clear-sky reflectance, brightness temperature => cloud detection/retrieval

- **Theoretical cloud reflectance & emittance models**

  describes angular variation for range of re and □=> cloud detection/retrieval

METHODOLOGY FOR EACH IMAGE TIME



Process each image as a sequence of pixel groups (tiles)

CLOUD MASK

- To detect clouds, the radiances for cloud-free (clear) scene must be known

- Determine clear-sky albedos and surface emissivities after initial processing of data

    - start with CERES values and update

- Use RUC surface temperatures & profiles to estimate clear-sky brightness temperatures

- Must account for angular dependence: bidirectional reflectance models to estimate clear-sky reflectance for each pixel

- Estimate thresholds based on uncertainties in models & spatial/temporal variability of the clear radiances

CLEAR-SKY RADIANCE CHARACTERIZATION

- **Predict radiance a given satellite sensor would measure for each channel if no clouds are present**

- **Estimate uncertainty based on spatial & temporal variability & angular model errors**

- **Develop set of spectral thresholds for each channel**

  - Solar, uses reflectance, □

  - IR, use temperature, T

  brightness temperature difference, BTD = $T_{□1}$ -$T_{□2}$

  typically, BTD(3.7-11) or BTD(11-12)

CLEAR-SKY REFLECTANCE, SOLAR

- **Estimate overhead-sun albedo, $\square_o = \square(\mu_o = 1)$**

  derived empirically with initial runs usingCERES VIRS data,
  then updated for each month using GOES

- **Estimate albedo at given local time, $\square(\mu_o) = \square_o \, \square_o(\mu_o)$**

  directional reflectance model $\square_o(\mu_o)$ derived for each IGBP type using VIRS

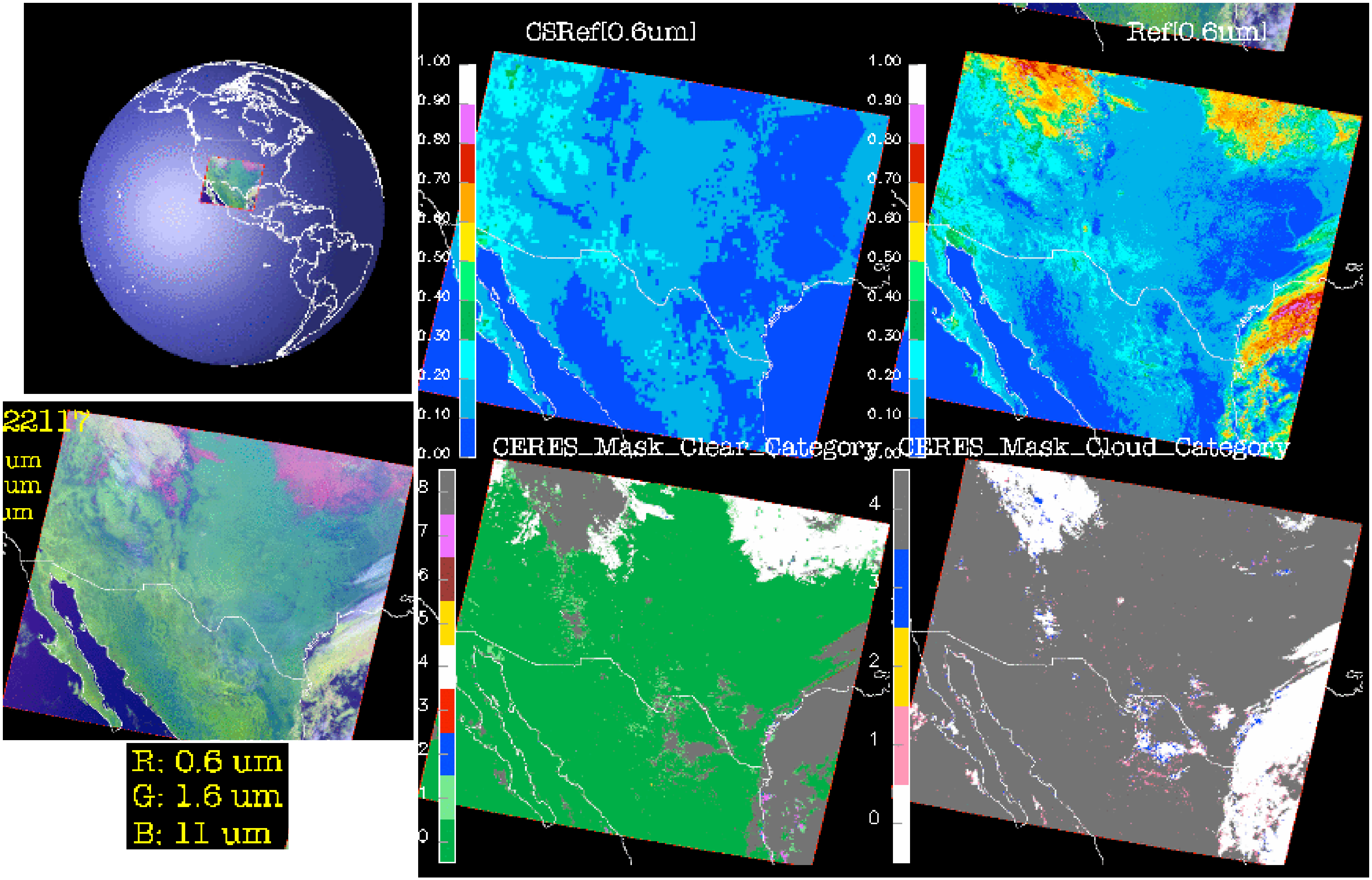
- **Estimate reflectance for given viewing angles, $\square(\mu_o, \mu, \square) = \square(\mu_o) \, \square(\mu_o, \mu, \square)$**

  bidirectional reflectance (BRDF) model $\square$ selected for each surface type

  from Kriebel (1978), Minnis & Harrison (1984), Suttles et al. (1988)

- **Add uncertainty to set reflectance threshold, $\square_T(\mu_o, \mu, \square) = \square + \square\square(\mu_o, \mu, \square)$**

PREDICTED CLEAR-SKY & OBSERVED VIS REFLECTANCE & CLOUD MASK
1700 UTC,12/21/00



CLEAR-SKY TEMPERATURE, INFRARED

- **Estimate surface emissivity, $\epsilon_s(x,y)$**

  derived empirically with using ISCCP AVHRR DX, VIRS, then Terra MODIS; water & snow theoretical models

- **Estimate radiance leaving the surface, $L_s = \epsilon_s B(T_{skin}) + (1-\epsilon_s)L_{ad}$**

  L_{ad} = downwelling atmo radiation, T_{skin} = skin temperature from model / obs

- **Estimate TOA brightness temperature, $B(T_{cs}) = (1-\epsilon_a)L_s + \epsilon_a\ L_{au}$**

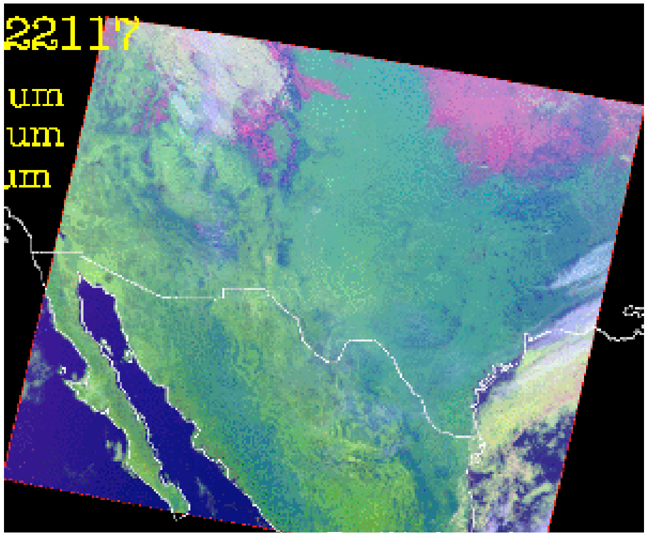
  L_{au} = upwelling atmo radiation, ϵ_a = effective emissivity of atmo

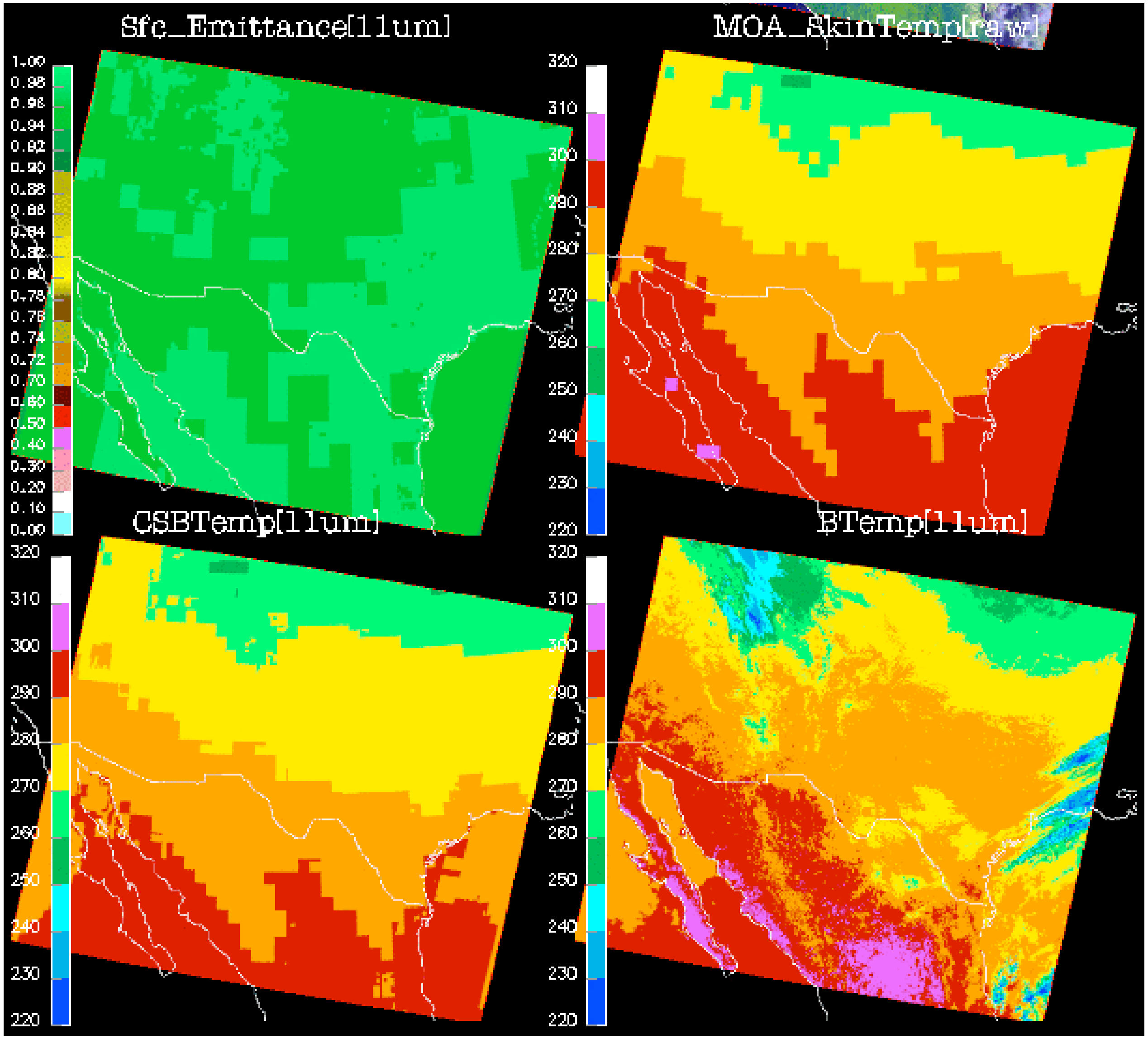
  layer absorption emission computed using T/RH profile, correlated k-dist

- **Add uncertainty to set T or BTD thresholds, $T_T(\mu) = T_{cs}(\mu) + \Delta T(\mu)$**

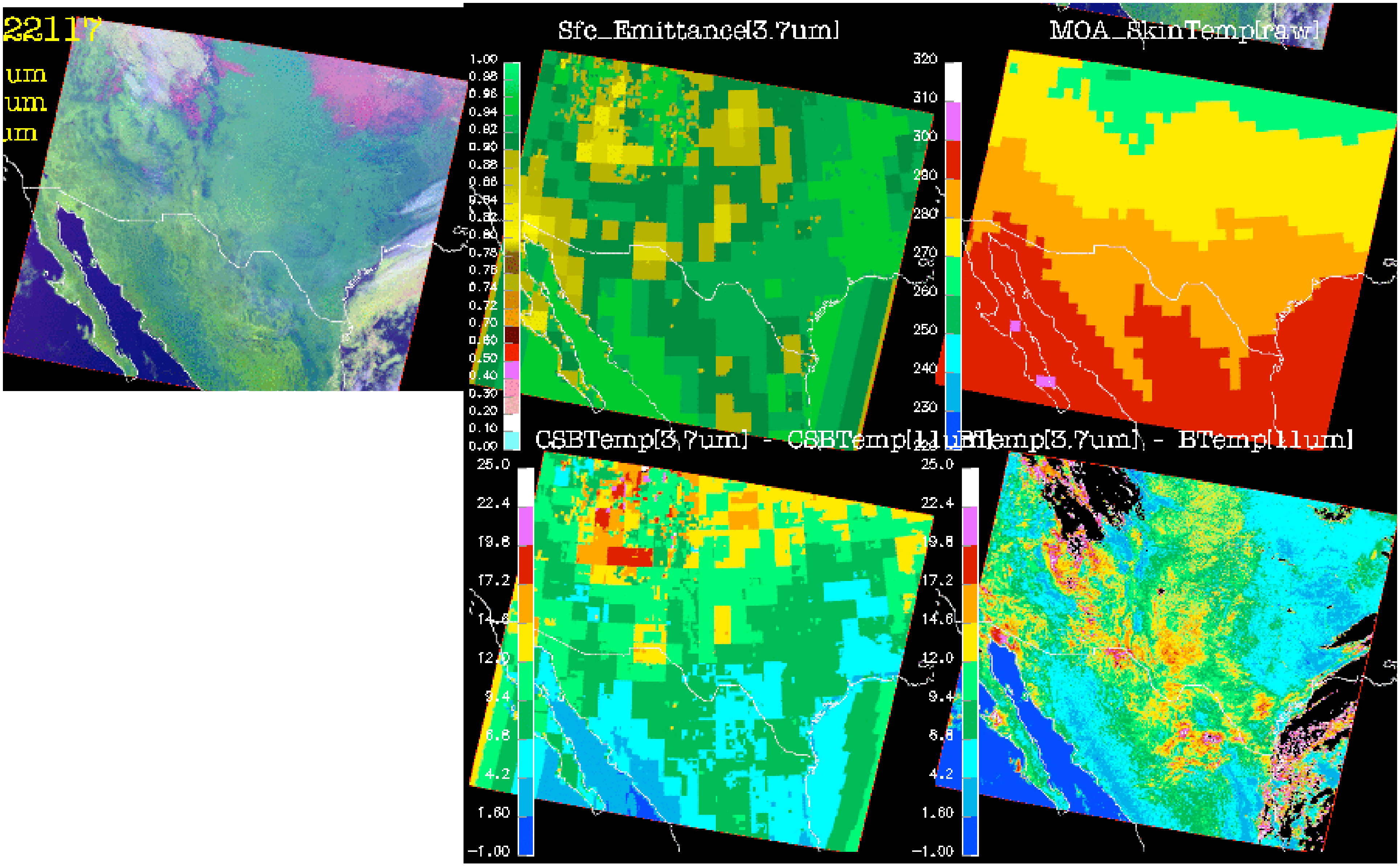
  - reflected solar component included in 3.7-4.0 µm estimate

PREDICTED CLEAR-SKY & OBSERVED IR TEMPERATURE
1700 UTC,12/21/00

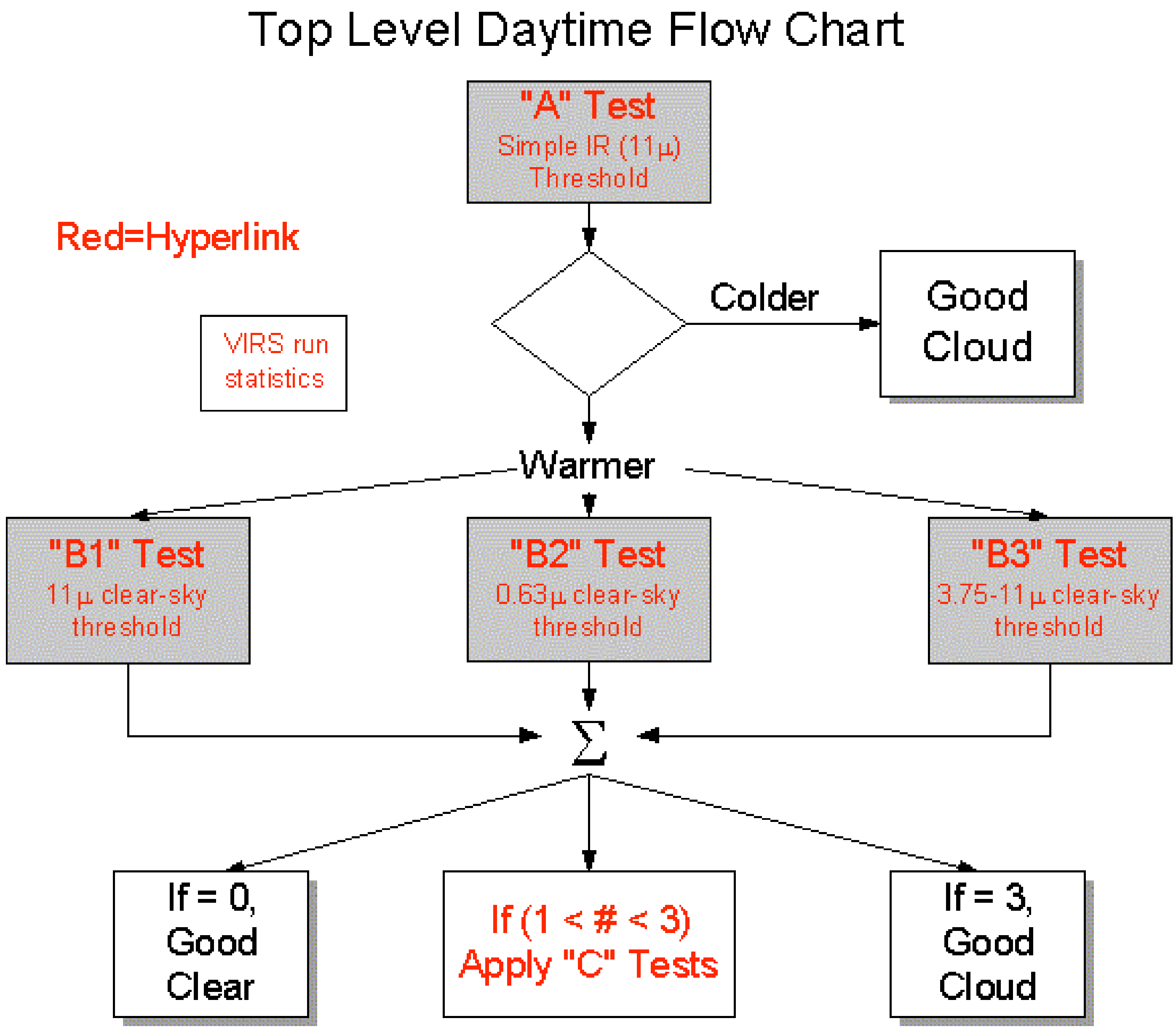


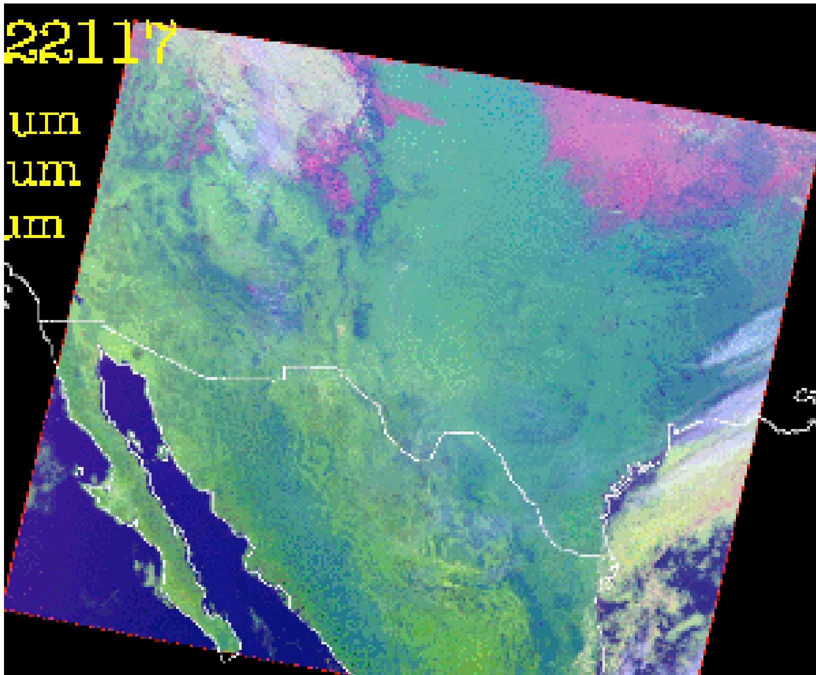


PREDICTED CLEAR-SKY & OBSERVED BTD (3.7 - 11)
1700 UTC,12/21/00

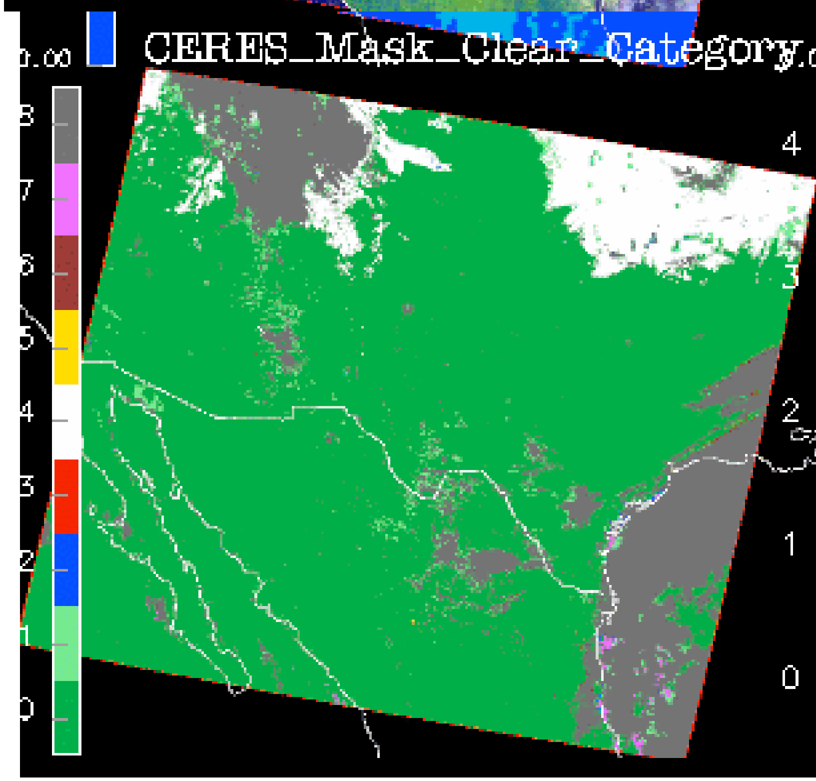


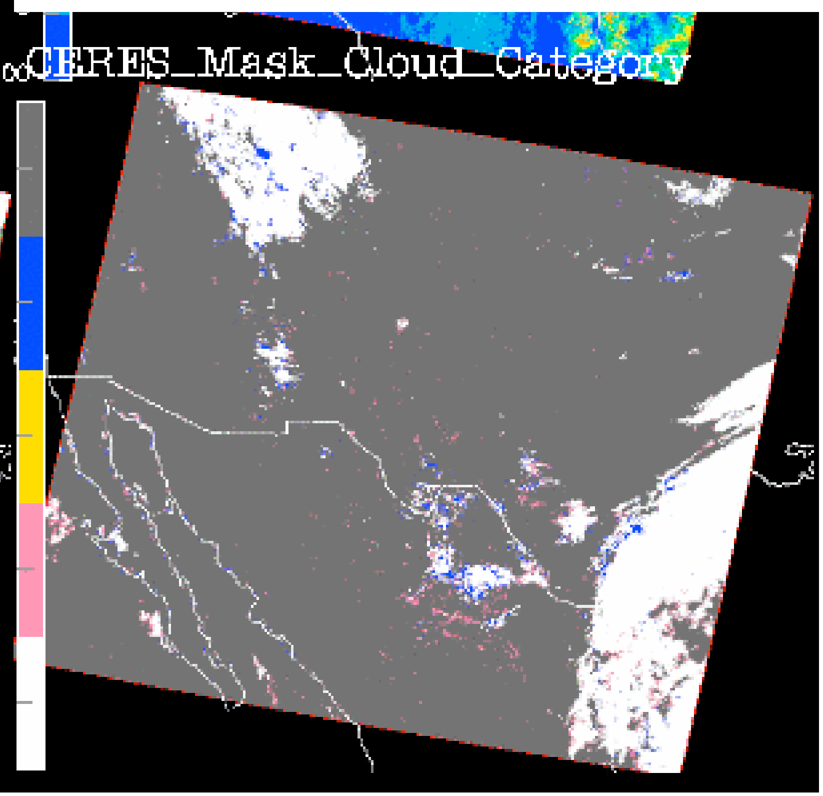
STANDARD DAYTIME MASK ALGORITHM



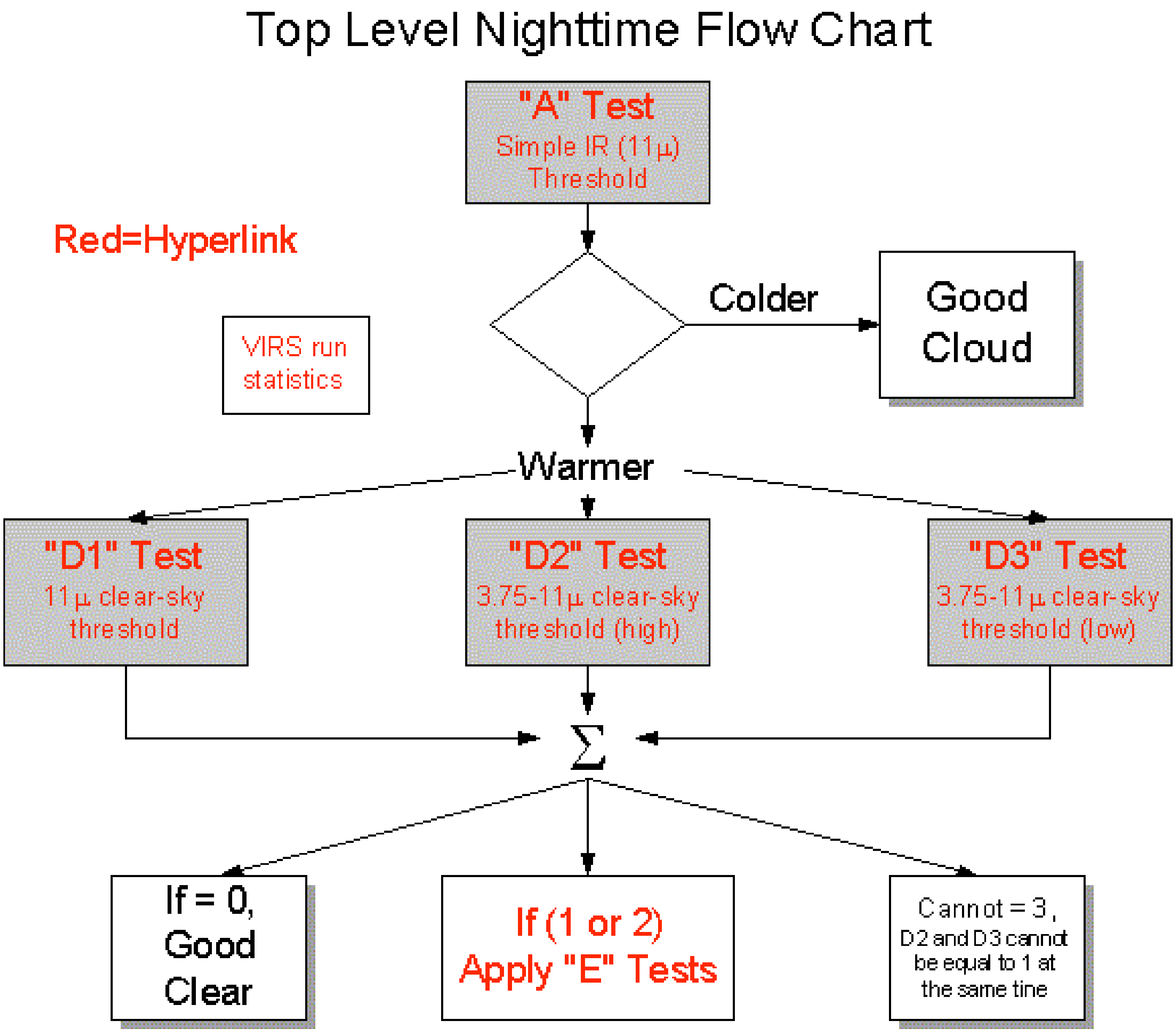


CERES CLOUD MASK 1700 UTC,12/21/00

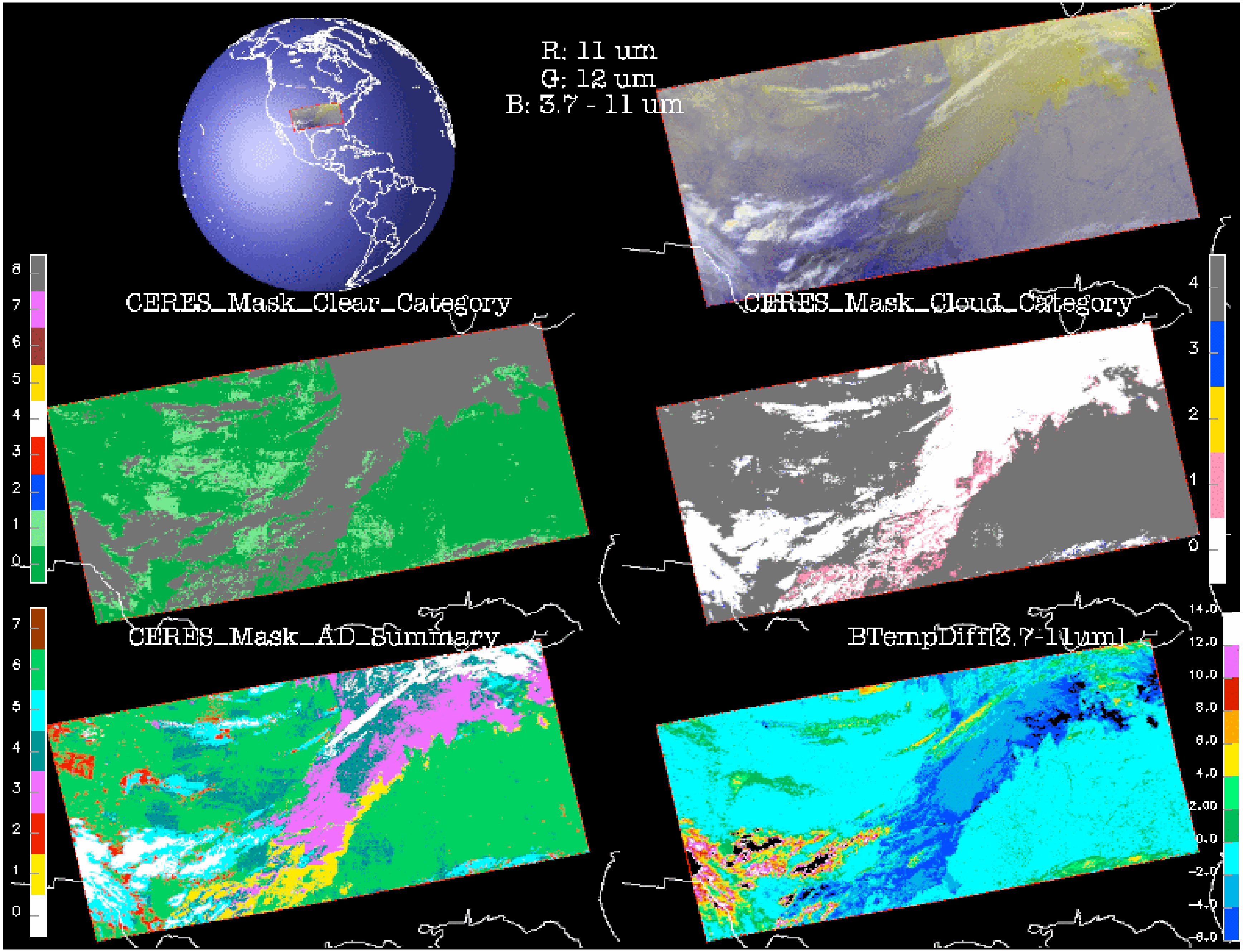




STANDARD NIGHTTIME MASK ALGORITHM



CERES CLOUD MASK & BTD(3.7 - 11) REFLECTANCE 0400 UTC,12/01/00



DAYTIME CLOUD RETRIEVALS

- **VISST (Visible, infrared, solar-infrared, split-window technique)**
  - **physically based method using 0.65, 3.7, 11, & 12 μm**
  - **for cloudy pixels, match radiances to model values**
- **Yields more accurate cloud temperatures than simpler methods**
  - **adjusts temperature (altitude) of thin clouds**
- **Provides basis for determining phase**
  - **in most cases, ice & water models are distinct**

Daytime Cloud Property Retrievals

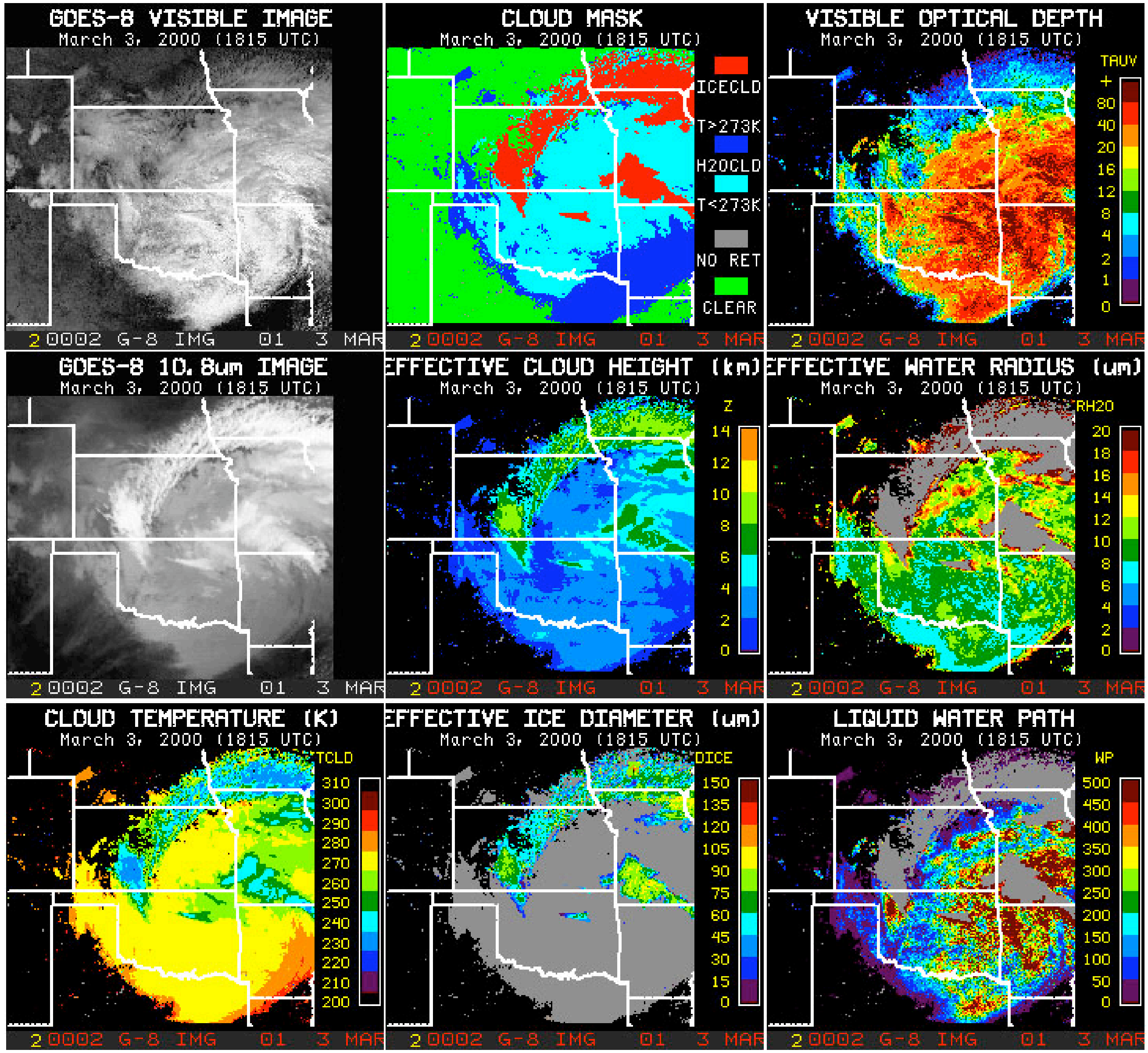
- Derive cloud properties by matching observed radiances to model calculations for water droplets ($2 < r_e < 32$ μm) and ice crystals ($6 < D_e < 135$ μm) through reflectance and emittance parameterizations
- 3.9 μm (GOES Channel 2) used for particle size retrieval
- Particle phase determined by:
  - (1) Best available model solution
  - (2) $T_{10.8}$ - $T_{12.0}$ Difference
  - (3) Visible/IR Layer Retrieval
  - (4) Retrieved Cloud Temperature

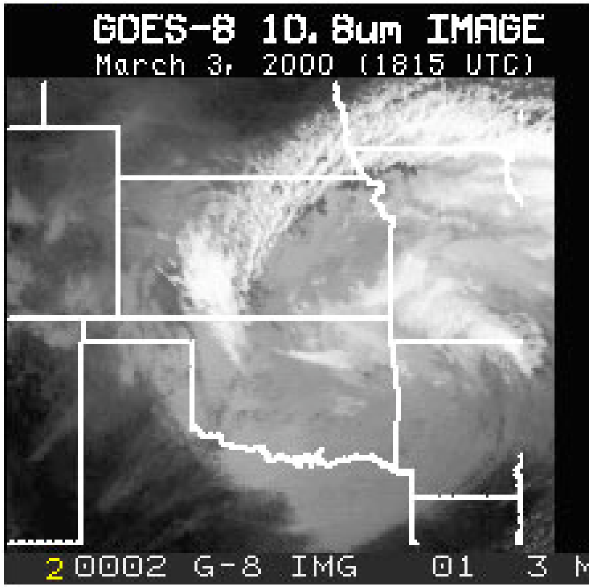
Cloud Tau, phase, r_e (D_e), LWP (IWP), Z_{cld} , T_{cld}

Cloud properties from GOES-8

1815 UTC

March 3, 2000

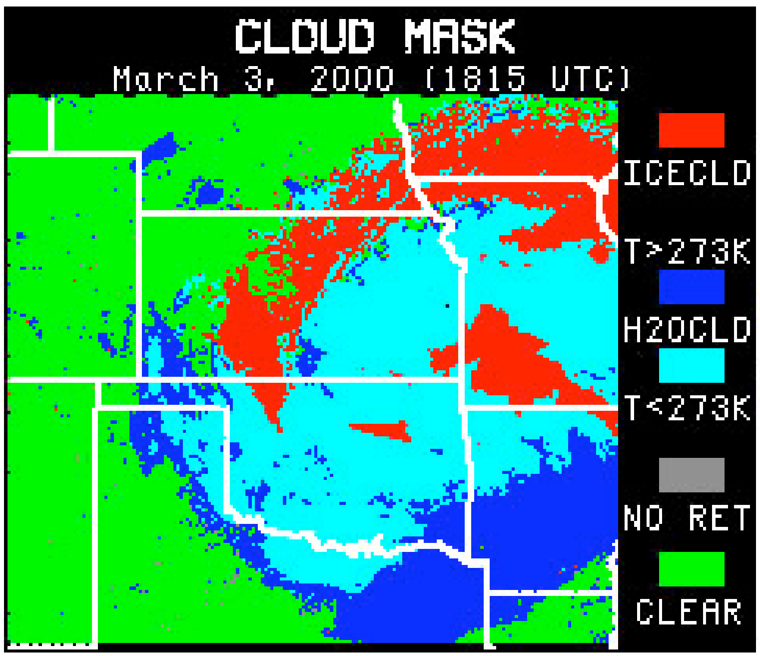


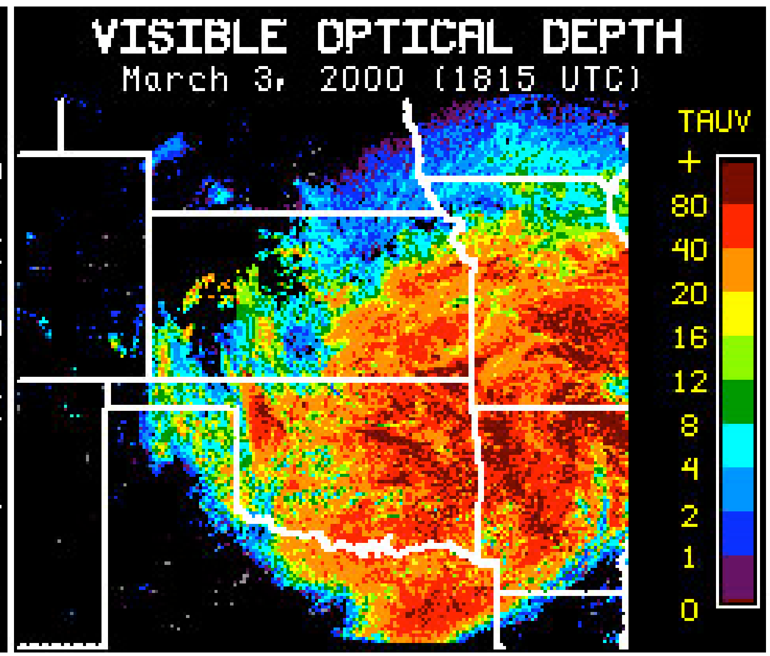


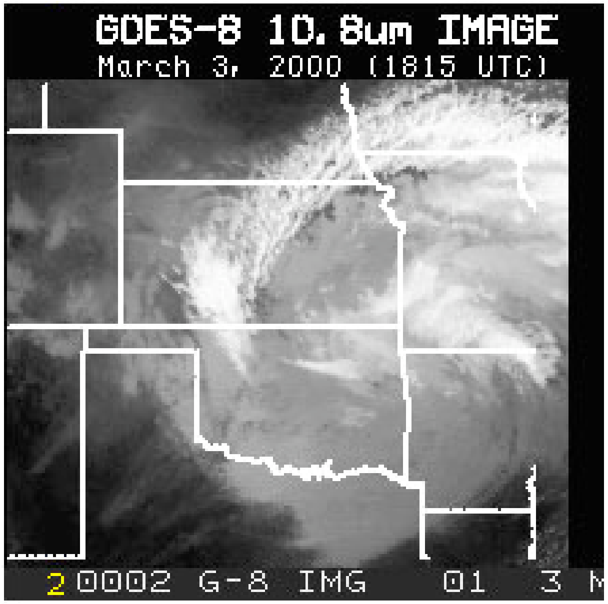
Cloud mask & optical depths from GOES-8

1815 UTC

March 3, 2000



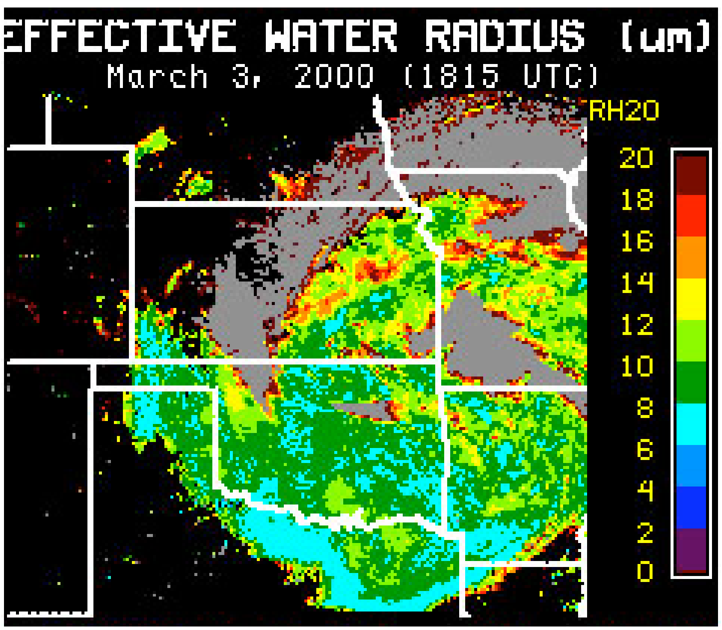


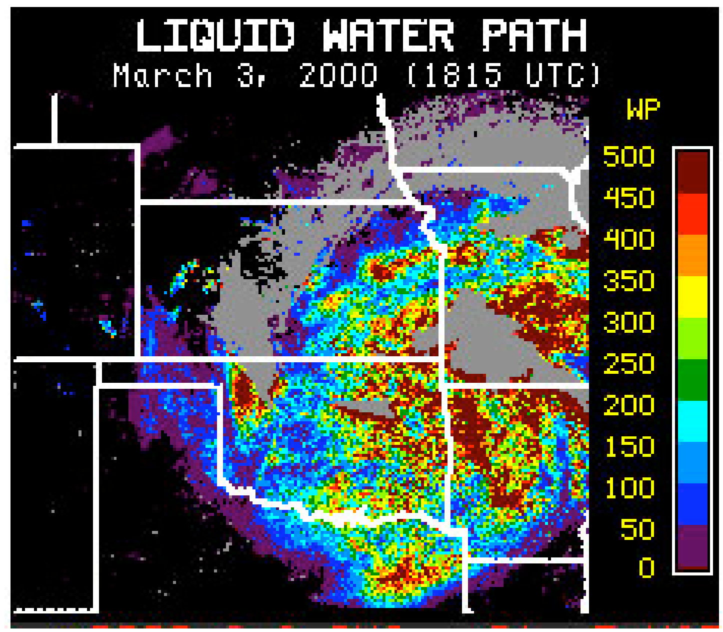


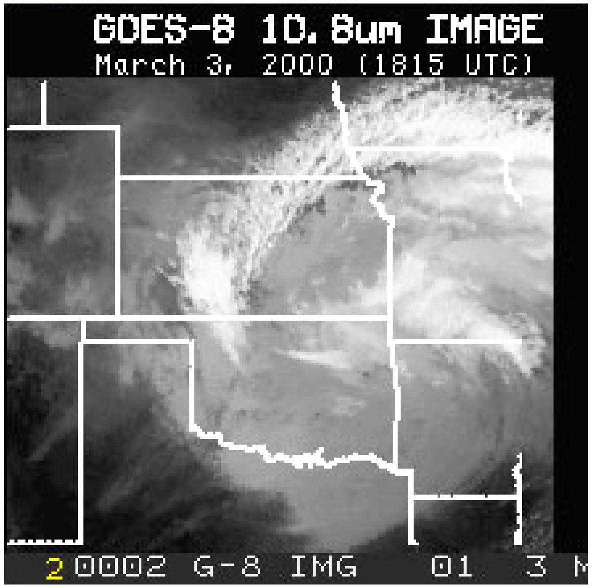
Cloud droplet radius & LWP from GOES-8

1815 UTC

March 3, 2000



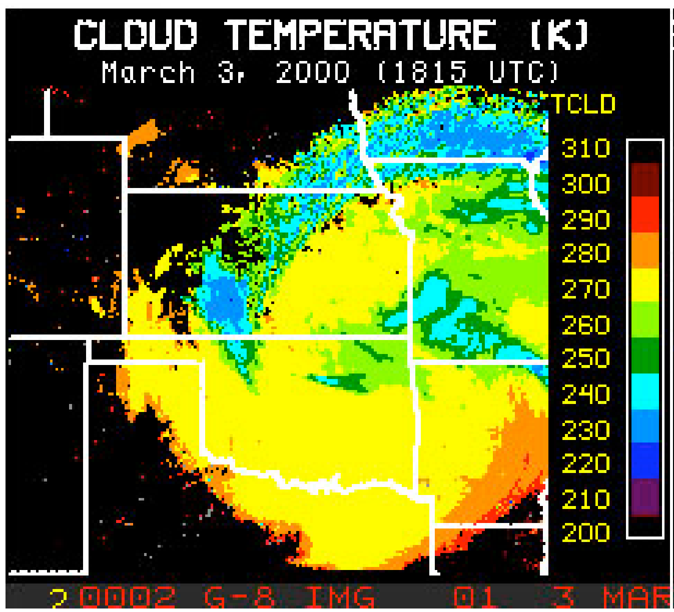


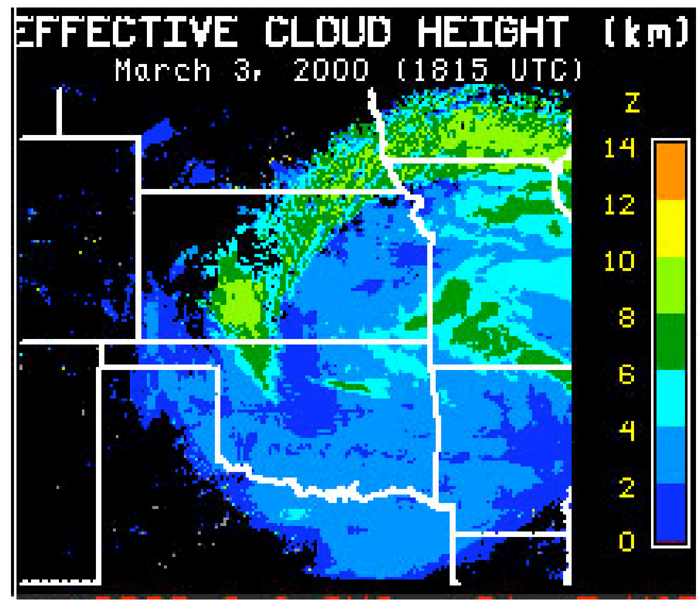


Cloud-top temperature
& height from GOES-8

1815 UTC

March 3, 2000





ARM-Sponsored Comparisons (March 2000)

Comparison of Surface, GOES and Aircraft Results (~10 hours)